

WATER RELATIONS AND COMMUNITY COMPOSITION IN THREE BLUE FAN PALM OASES ACROSS THE CALIFORNIAN-SONORAN BIOME TRANSITION

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ABSTRACT—The blue fan palm (*Erythea armata*) oases of the Sierra San Pedro Mártir, Baja California, Mexico, are unique not only because of their occurrence on the Pacific side of the Peninsular Range, but also because they span a steep transition from Mediterranean-type scrubland and piñon woodland to the Vizcaíno and Colorado phases of the Sonoran Desert to the south and east. Here we describe soil-water relations and community composition in 3 grazed Pacific-side palm oases along a 20-km transect from Sonoran Desert at 700 m elevation (El Rincón), to an ecotone of mixed desert scrub, coastal scrub, and mountain chaparral at 900 m (San Miguel), to chaparral and piñon-juniper woodland at 1,200 m (El Represo). Soil water was measured by using a neutron probe during an annual cycle. The palm grove at El Rincón had low soil water in the arroyo and oasis throughout the study period, although water was always present in pools both upstream and downstream. At San Miguel, pools were dry most of the time, but both the arroyo and oasis had moderate soil water, and the arroyo apparently received moisture by subsurface flow from nearby highlands. The seemingly dry oasis at El Represo had moderately high soil water, which was apparently maintained by a local seep. A total of 193 taxa were recorded, but only 30 (15.5%) were common to all 3 sites. In these communities, the Californian component diminished from 40 to 29% across the Californian-Sonoran transition, while Sonoran taxa decreased from 41 to 29% in the opposite direction. Determination of the most important species across this biome boundary revealed a strong Sonoran influence, even in the chaparral-piñon-juniper site. *Erythea armata* seems to be a species particularly adapted to this arid transitional region.

RESUMEN—Los oasis de palma azul (*Erythea armata*) de la Sierra San Pedro Mártir, Baja California, México son únicos, no sólo porque se encuentran en la vertiente del Pacífico de la cordillera peninsular, sino también porque ocurren en una zona de transición que abarca desde matorrales y bosques californianos, hasta las fases Vizcaíno y Colorado del Desierto Sonorense hacia el sur y el este. Describimos las relaciones hídricas y composición de la comunidad de 3 oasis de palmeras en el lado del Pacífico, ubicados a lo largo de un transecto de 20 km en una región pastoreada que comienza en el Desierto Sonorense a 700 m (El Rincón), continúa a través de un ecotono con una mezcla de matorral costero y desértico con chaparral a 900 m (San Miguel), y termina en bosque de piñón y junípero a 1,200 m (El Represo). El contenido hídrico del suelo se midió con una sonda de neutrones durante un ciclo anual. El Rincón tuvo valores bajos de humedad en el arroyo y en el oasis a través del período de estudio, a pesar de tener pozas permanentes de agua río arriba y río abajo. Las pozas en San Miguel permanecieron secas casi todo el tiempo del estudio, pero tanto el arroyo como el oasis registraron contenidos hídricos moderados y el arroyo aparentemente recibió humedad subsuperficial proveniente de tierra alta cercana. A pesar de su apariencia seca, el palmar en El Represo registró contenidos hídricos moderadamente altos, mantenidos por un manantial. Se registró un total de 193 taxa, pero sólo 30 de ellos (15.5%) se encontraron en cada uno de los 3 oasis. En estas comunidades, el componente californiano decreció de 40 a 29% a través de la transición Californiana-Sonorense, mientras que los taxa sonorenses disminuyeron de 41 a 29% en dirección opuesta. Al determinar las especies más importantes a través del límite de este bioma se encontró una fuerte presencia de elementos del Desierto Sonorense aún en la zona de pino piñonero. *Erythea armata* parece ser una especie particularmente bien adaptada a esta árida región transicional.

A significant portion of watercourses along the base of the Peninsular Range in the state of Baja California (i.e., the peninsula north of 28°N) is inhabited by populations of palms in the genera *Erythea* and *Washingtonia*, which have been referred to in the popular literature as “palm canyons” or “palm oases” (Henderson, 1964, 1971; Cornett, 1989). Little scientific information is available on these picturesque plant communities.

The palm oases of Baja California were important for the subsistence of indigenous peoples until early in the 1900s, providing shade, materials for shelters, water, game, and large quantities of palm seeds and fruit, from which they made both food and drink (Castetter and Bell, 1951; Moran, 1978; Cornett, 1989). By the mid 1900s, most of the oases in the northern half of the peninsula had been largely depopulated as a result of the collapse of the indigenous populations, becoming interesting destinations for explorers, adventurers, and off-roaders (Gardner, 1961; Henderson, 1964, 1971). By contrast, most palm oases in Baja California Sur (south of 28°N) have been continuously inhabited by aborigines and mestizos since mission times, and thus have been greatly altered by subsistence farming (Maya et al., 1997). Farming by either aborigines or mestizos has generally not been feasible in the Californian (e.g., Mediterranean-type) climate of the north because of the lack of summer precipitation and the small size of streams.

Four palms (*Erythea armata*, *E. brandegeei*, *Washingtonia robusta*, and *W. filifera*) are native to the Baja California peninsula, but although they are considered keystone species in its wetlands (Felger, 1999), their taxonomy remains uncertain (Wiggins, 1980; Felger, 1999). Following the nomenclature of Wiggins (1980), we refer to the genus as *Erythea* rather than *Brahea*. *Erythea armata* and *W. filifera* are native to the area influenced by the summer-dry Californian climate, while *E. brandegeei* and *W. robusta* are restricted to the tropical (summer rain and winter drought) southern peninsula. An indication of the adaptation of *E. armata* to the more extreme Mediterranean-type conditions is that the dull bluish or grayish cast of the leaves seems to be a response to aridity, winter freezing, or both (Felger, 1999).

A majority of the 171 palm oases reported by Maya et al. (1997) in Baja California Sur are inhabited by *W. robusta*, with the introduced date palm, *Phoenix dactylifera*, apparently displacing *E. brandegeei* in many places, including the large oasis at San Ignacio (Arriaga et al., 1997). In the

north, more than 150 *E. armata* oases occur in a largely roadless area along the southern margin of the Sierra San Pedro Mártir (Minnich and Franco-Vizcaíno, 1998). This is a unique distribution, because the only other known oasis on the Pacific side of the Peninsular Range is at Valle de las Palmas, southwest of Tecate, but it is populated by *W. filifera* (Moran, 1978).

Both *Washingtonia* and *Erythea* were widely distributed over what is now California and Baja California during the Tertiary (65 to 2.6 million years ago) (Axelrod, 1979; Thorne, 1986; Millar, 1996). These taxa apparently became increasingly restricted to favorable riparian habitats as the climate became drier beginning in the late Miocene (7 to 5 million years ago). This drying intensified as rain shadows developed with the buildup of the Peninsular Ranges and the Sierras Madre and Nevada during the late Pliocene (~2 million years ago), and was exacerbated by the increasing summer drought that gave rise to the present Mediterranean-type pattern. The summer-dry pattern also developed in late Pliocene to early Pleistocene times (2 to 1.8 million years ago) and was due to a number of factors, including the strengthening of the subtropical high-pressure zones, decreases in global temperatures leading to glaciation at high latitudes, and the consequent development of cold currents offshore (Axelrod, 1979; Thorne, 1986; Millar, 1996).

The current geographic distribution of *E. armata* remains an open question, but we consider the range indicated in Fig. 1 to be roughly correct. Its northernmost occurrence is in the Sierra Juárez 25 km south of the Mexico-USA boundary (Moran, 1978), and its southern limit seems to be in Sierra La Libertad (28°37'N). Specimens from Sierra San Francisco in Baja California Sur (27°32'N) seem to belong to the sister hesper palm, *E. brandegeei* (Felger, 1999). A small population also inhabits Isla Angel de la Guarda in the Gulf of California (Moran, 1978), but the species does not occur in Sonora, as reported by Schnabel (1964) (R. Felger, pers. comm.).

Although the palm oases of the southern Sierra San Pedro Mártir were extensively grazed during the 1900s, the region is sparsely populated and remains largely unchanged since mission times (Minnich and Franco-Vizcaíno, 1998). The largest cluster of *E. armata* populations occurs along the southern limit of the Californian Floristic Province (Minnich and Franco-Vizcaíno, 1998). Here, the coastal sage scrub, chaparral, and conifer forests of

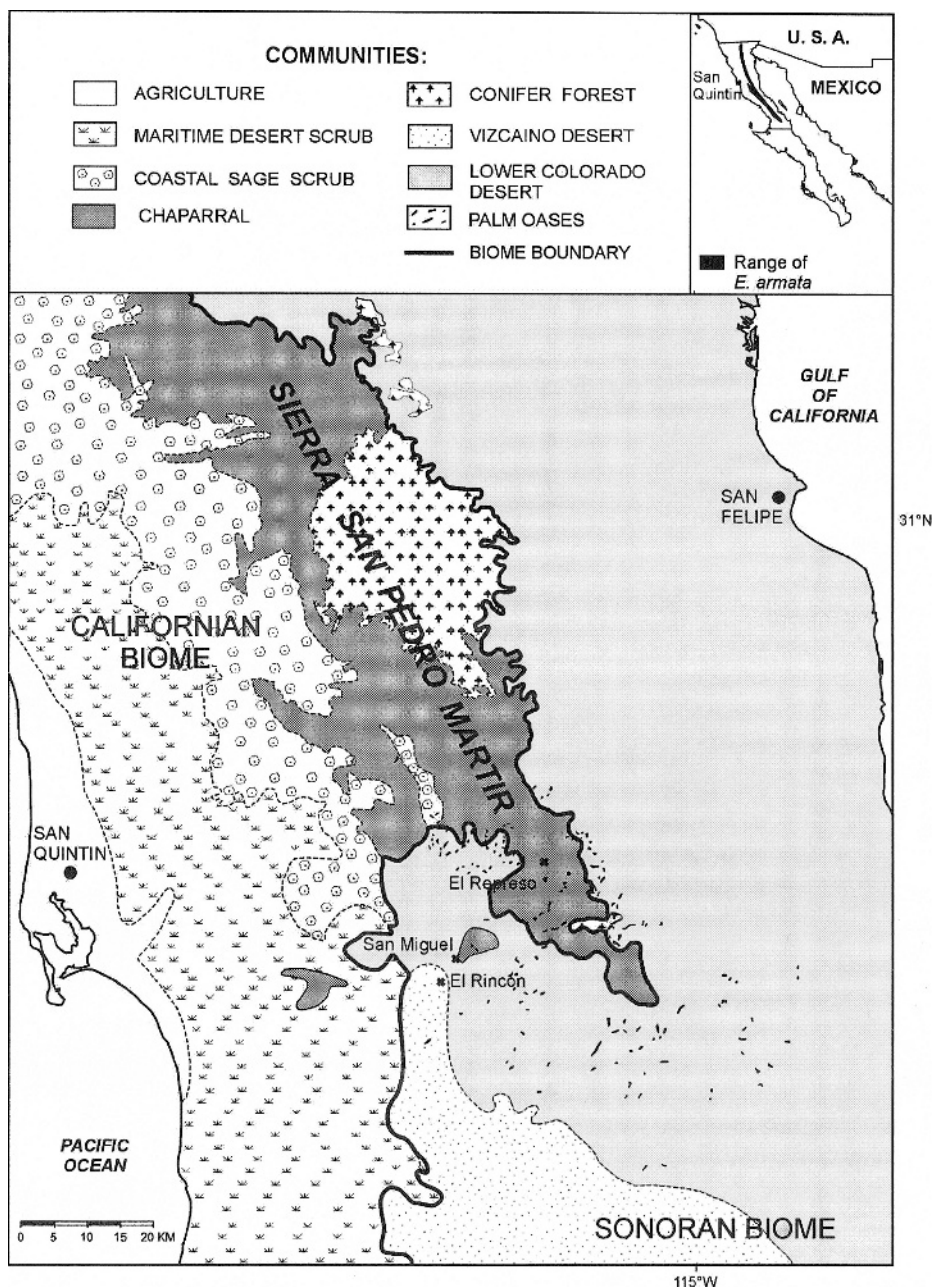


FIG. 1—Vegetation map of the Sierra San Pedro Mártir region, Baja California, Mexico (after Minnich and Franco-Vizcaino, 1998), showing locations of the study sites, and geographic range of *Erythea armata*.

the North American Mediterranean region transition toward 2 phases of the Sonoran Desert (Fig. 1): the Vizcaino to the south and Lower Colorado to the east (Shreve and Wiggins, 1964).

Such broad-scale biome boundaries are usually defined by steep gradients in climatic features

(Gosz, 1992). They might also present threshold phenomena, such that small changes in temperature or in the timing and amounts of precipitation could affect the distributions of organisms or elicit non-linear responses in key ecological processes (Gosz, 1992). The Califor-

nian-Sonoran transition in the southern Sierra San Pedro Mártir could thus be a good indicator of changes, past and current, in the global climate.

Vogl and McHargue (1966), who studied 24 oases along the San Andreas Earthquake Fault in the Coachella Valley of southern California, distinguished between “wash oases,” associated with canyons and stream beds with intermittent or permanent surface water, and “seep oases” that depend on underground water emanating along geological faults. However, quantitative measurements of water content in soil profiles of palm oases are apparently lacking. Four possible sources of water have been reported for oases in California (Schwenkmeyer, 1986): 1) percolation of subsurface water through fractures associated with geological faults, 2) formation of arroyos in canyons from mountain runoff, 3) water percolation through small cracks in granite, and 4) accumulation of mountain runoff at the base of alluvial fans.

The aims of this study were to determine the potential sources of water in 3 oases along a transect from desert scrub to piñon-juniper (*Pinus-juniperus*) woodland in the southern Sierra San Pedro Mártir, and to compare the structure and composition of plant communities across this Californian-Sonoran transition.

METHODS—Study Area—In the southern highlands of the Sierra San Pedro Mártir, the peninsular batholith rapidly loses elevation and its granitic rocks are overlain by numerous layers of cemented volcanic ash (tuff) extruded from the Pico Matomí and Cerro Canelo volcanoes during Miocene times (Gastil et al., 1975; INEGI, 2001). The largest concentrations of blue fan palm oases occur along these tilted volcanic mesa lands of the peninsular divide that are the headwaters of Arroyos Grande, San Miguel, and El Portezuelo, which drain toward the Pacific, and Arroyo Matomí, which drains toward the Gulf of California.

We selected 3 oases accessible by dirt road on the southwestern flank of the Sierra San Pedro Mártir: El Rincón, San Miguel, and El Represo (Fig. 1). Strictly speaking, the Californian-Sonoran transition here runs NW to SE, but our study sites lie along a 20-km section of road that runs SW to NE (Fig. 1), with elevation increasing from about 700 to 1,200 m. Annual precipitation in our study region is about 240 mm, with about 120 mm falling in winter, i.e., October to May (Minnich and Franco-Vizcaíno, 2005). Mean annual temperature, estimated from data in Miranda et al. (1991), is about 20°C, with average July maxima around 43°C and average January minima of 3°C.

Soil water content was measured by using a neutron probe (Hydroprobe Moisture Depth Gauge, Campbell Pacific Nuclear Corporation, Martinez, California) in 5-cm diameter poly-vinyl chloride (PVC) access tubes during an entire annual cycle. Single access tubes were installed on the eastern side of each arroyo along the

gradient of water availability, similar to the zonation proposed by Vogl and McHargue (1966): within the watercourse, in the oasis as defined by the presence of *E. armata*, and in the desert scrub adjacent to, but outside the oasis (i.e., ecotonal). At El Represo an additional access tube was installed within the oasis in a small meadow of *Juncus balticus*, which together with salt crusts, indicated the presence of a seep. Neutron probe measurements were made in depth increments of 20 cm to rock contact (40 to 80 cm). Neutron probe data were used to calculate gravimetric water content by using calibration curves for similar sandy soils in the Sierra San Pedro Mártir as described in Franco-Vizcaíno et al. (2002). To compare water content of soil profiles having different depths, the percent gravimetric water contents ($\text{Mg H}_2\text{O} / \text{Mg soil} \times 100$) were averaged over all depth increments. Precipitation was measured at El Rincón by using a digital rain gauge with accumulation counter.

The vegetation at El Rincón is desert scrub dominated by arborescent succulents typical of the Vizcaíno Desert, such as cardón (*Pachycereus pringlei*) and boojum tree (*Fouquieria columnaris*) (Figs. 1, 3). San Miguel has elements of both coastal (e.g., coastal sage scrub and maritime desert scrub as described in Minnich and Franco-Vizcaíno, 1998) and Sonoran Desert scrub, as well as chaparral. The complex of oases at El Represo is embedded in chaparral and piñon-juniper woodland.

We characterized the structure of perennial plant communities by using the line-intercept method and calculated the importance values of species in a manner similar to that described by Vogl and McHargue (1966), but using methods in Franco-López and De la Cruz (1985) and Strong (1966). At each site, six 30-m transects were laid out at random, roughly along the same line as the neutron probe access tubes, but including both banks of the arroyo and adjacent desert ecotone.

We developed a floristic inventory of the 3 sites by collecting at different seasons during the period 1999 to 2003. Taxa identified to species were classified as to their distribution (Californian Floristic Province, Sonoran Desert, continental, cosmopolitan, or introduced) by consulting standard references (Wiggins, 1980; Hickman, 1993; University of California, Berkeley, 2006) and other sources (Gentry, 1978; Rebman, 1995).

RESULTS AND DISCUSSION—Water Relations—This study coincided with the beginning of a period of profound drought in northern Baja California, and only 96.6 mm of precipitation were recorded at the rain gauge at El Rincón from February 2001 to March 2002 (Fig. 2). More than half this amount fell during winter 2001, but only 28.5 mm were recorded during fall and winter 2002. The remnants of tropical storm Juliette passed over the region on 30 September 2001, but apparently little rain fell at our study sites.

At all 3 oasis-desert scrub ecotones, the general trend in soil moisture was drying down to minimum levels (2 to 5%) after the relatively wet winter of 2001 (Fig. 2). There were no differences

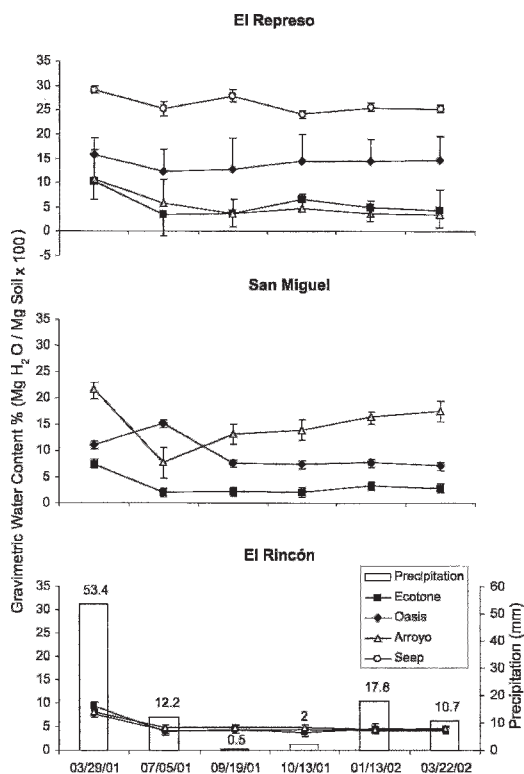


FIG. 2—Changes in soil water in the arroyo, oasis, and desert ecotone at the 3 sites in the Sierra San Pedro Mártir region, Baja California, Mexico, during the study period. Water content in the soil profile ($\% \pm SE$) was determined by averaging neutron probe readings over all 20-cm depth increments (rock contact ranged from 40 to 80 cm). Precipitation was measured at El Rincón by using a tipping-bucket rain gauge with accumulation counter.

in soil moisture content between arroyo, oasis, and desert ecotone at El Rincón, while substantial differences occurred at the other 2 sites. At El Represo, the arroyo was as dry as the ecotone, but at San Miguel the arroyo was consistently wetter than the ecotone, with soil water contents trending upwards from 7 to 15%, apparently in response to base flow associated with summer precipitation and the remnants of tropical storm Juliette. The oasis zones at both San Miguel and El Represo had moderate soil water content, but El Represo remained relatively constant at around 15%, while San Miguel increased to 15% in response to early precipitation and then decreased to about 7%. Examination of the raw data showed that variability in water content was mostly because of higher moisture in the deeper soil layers, while the surface

layers were generally dry. The *Juncus balticus* meadow at El Represo showed consistently moist conditions during the entire period, with a slight downward trend from 29 to 26%. Low variability here indicated that moisture was uniformly distributed throughout the soil profile. These results suggested that the seep at El Represo helped maintain moist conditions in the oasis zone.

During the study period, El Rincón had flowing water in rocky pools much of the time both upstream (~ 200 m) and downstream (~ 100 m) from the location of the neutron probe access tubes, but the study site itself was arid. At San Miguel, rocky pools downstream were dry most of the time, but there was evidence of seepage (salt crusts along the stream banks and scattered populations of *Juncus acutus* in the arroyo) within the study site. Although San Miguel appeared arid, our results indicated that substantial soil moisture was available both within the oasis and in the arroyo (Fig. 2). Thus, while El Represo was clearly a seep oasis, and El Rincón was a wash oasis dependent on runoff from nearby uplands, San Miguel appeared to be a mixture of the 2 types.

In the southern Sierra San Pedro Mártir, a few palm groves are clearly associated with geologic faults, but our results indicated that mountain runoff was the most important source of water for oases in the region. We suggest that the layers of cemented volcanic ash, which slant in different directions based on their location throughout this vast region, store precipitation and release moisture at their contact with the peninsular batholith below. During flights over the region, we observed palm oases in watercourses that apparently originate at springs along these zones of contact between volcanic and granitic rocks. Percolation of water through small cracks in granite (i.e., mechanism 3 of Schwenkmeyer, 1986) might explain the unusual occurrence of isolated populations of upland palms that occur only in association with certain forms of granitic boulders, sometimes hundreds of meters above the arroyos (pers. obser.). We are not aware of any oases occurring at the base of alluvial fans in the state of Baja California.

Composition and Distributional Affinities of the Vegetation—We inventoried 193 taxa at the 3 oases, representing 59 plant families. Families with the most genera were Asteraceae (28), Fabaceae (10), Cactaceae (9), and Euphorbiaceae (7). During our multi-year, multi-season inventory, we recorded 107 annual and perennial taxa at El Represo, 100 at San Miguel, and 107 at El

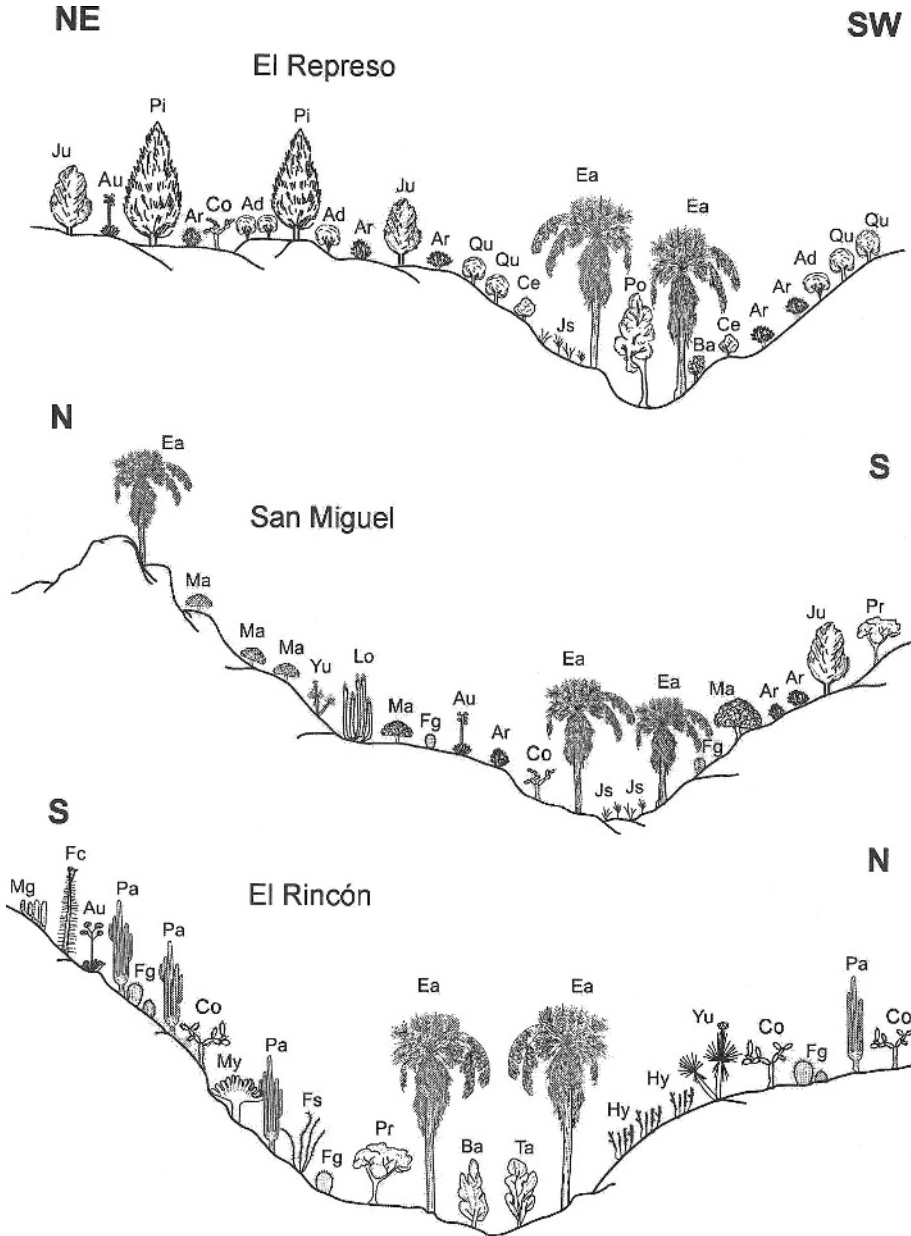


FIG. 3.—Schematic profiles of the vegetation at the 3 blue fan palm oases in the Sierra San Pedro Mártir region, Baja California, Mexico. The vegetation at El Rincón (700 m) was desert scrub dominated by arborescent succulents typical of the Vizcaíno phase of the Sonoran Desert, such as cardón (*Pachycereus pringlei*) and boojum tree (*Fouquieria columnaris*). At San Miguel (900 m), vegetation was a mixture of coastal scrub (i.e., maritime desert scrub and coastal sage scrub), Sonoran Desert scrub, and chaparral. At El Represo (1,200 m), the vegetation was a mixture of chaparral and piñon-juniper (*Pinus-Juniperus*) woodland. Ad *Adenostoma fasciculatum*, Au *Agave cerulata nelsonii*, Ar *Artemisia* spp., Ba *Baccharis* spp., Ce *Ceanothus leucodermis*, Co *Cylindropuntia* spp., Ea *Erythra armata*, Fg *Ferocactus gracilis*, Fc *Fouquieria columnaris*, Fs *Fouquieria splendens*, Hy *Hyptis emoryi*, Js *Juncus* spp., Ju *Juniperus californica*, Ma *Malosma laurina*, Mg *Machaerocereus gummosus*, My *Myrtilocactus cochal*, Pa *Pachycereus pringlei*, Pi *Pinus quadrifolia*, Po *Populus fremontii*, Pr *Prosopis glandulosa*, Pr *Prunus fremontii*, Qu *Quercus* spp., Ta *Tamarix ramosissima*, Yu *Yucca schidigera*.

TABLE 1—Numbers (*n*) and distributional affinities of vascular plant species recorded at 3 study sites in the Sierra San Pedro Mártir, Baja California, Mexico.

	El Represo Piñon-Juniper		San Miguel Coastal Scrub-Chaparral		El Rincón Desert Scrub		Total all 3 sites	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
Californian	43	40.2	41	41.0	31	29.0	72	37.3
Sonoran	31	29.0	26	26.0	44	41.1	58	30.1
Continental	22	20.6	18	18.0	17	15.9	34	17.6
Cosmopolitan	2	1.9	4	4.0	2	1.9	6	3.1
Introduced	4	3.7	5	5.0	9	8.4	10	5.2
Species not determined	5	4.7	6	6.0	4	3.7	13	6.7
Total	107		100		107		193	

Represo. The proportion of taxa exclusive to one site was 24.9% at El Represo, 10.9% at San Miguel, and 17.1% at El Rincón. El Represo and San Miguel shared 8.8% of their plant taxa, while El Represo and El Rincón shared 6.2% and San Miguel and El Rincón shared 16.6%. Only 30 taxa (15.5%) were common to all 3 sites. We recorded 60 mostly perennial taxa in the 30-m transects. In our transects, which covered 1 to 2 ha, the proportions of exclusive taxa were higher, while those of shared taxa were lower than in the inventories, which covered several hectares.

Of the taxa recorded in the inventories, 37% were classified as Californian, 30% were classified as Sonoran, and 21% were of wide distribution (continental and cosmopolitan) (Table 1). About 5% of all taxa recorded were exotic, and another 7% could not be identified to species. Nineteen peninsular endemics were recorded at the 3 sites (9.8%); of these, 8 were classified as Californian and 11 as Sonoran (Appendix).

The main difference in community composition across the Californian-Sonoran transition was an approximately 11% shift in the distributional affinities of taxa. That is, the number of Californian species declined from 43 at El Represo to 31 at El Rincón, while the number of Sonoran species decreased from 44 to 31 in the other direction (Table 1). The transitional site, San Miguel, had similar proportions of Californian and Sonoran taxa to El Represo, but twice as many cosmopolitan species (4) than the other sites. Thus, the transition occurred between San Miguel and El Rincón; this is strikingly evident on the ground, because boojum trees and cardón cacti drop out about 2 km NE of El Rincón (pers. obser.).

Analysis of the transect data revealed a pattern similar to that in the inventories (Table 2). At El

Represo, 3 of the 6 most important species were classified as Californian, 2 were continental, and 1 was Sonoran, while at San Miguel 1 species was Californian, 2 were continental, and 3 were Sonoran. At El Rincón 4 of the 6 were Sonoran and 2 were Californian. It should be noted that the transitional site, San Miguel, had the highest proportion of Californian taxa (46%), while El Represo and El Rincón each had about 38%. El Rincón had the highest proportion of Sonoran taxa (54%), while El Represo and San Miguel both had about 38%. The percentage of continental species declined from 12.5% to 4.2% between San Miguel and El Rincón, and one cosmopolitan taxon was recorded at each site. These results reiterate that the Californian-Sonoran transition occurred between San Miguel and El Rincón. The results also show the extent to which the upland coastal scrub-chaparral and piñon-juniper woodland (and indeed much of northwestern Baja California) are affected by the nearby Sonoran region, and also that the Californian influence extends into the coastal desert of the peninsula.

The mean ($\pm SD$) number of plant species recorded in the transects ($n = 6$) at the 3 sites was 25.7 ± 2.3 (López-Beltran, 2003). This is more than twice the average number (11) reported by Vogl and McHargue (1966) in the oases of southern California. But unlike their results, the most prevalent species in the Baja California oases were not phreatophytes, but rather coastal and desert scrub species (Table 2). These results are not strictly comparable with those of Vogl and McHargue (1966), however, because we did not stratify our transects to coincide with the zonation they used (arroyo, oasis, ecotone).

TABLE 2—Importance values and distributional affinities of the 6 most prevalent species, and percentages¹ of Californian, Sonoran, and continental species from random, 30-m transects ($n = 6$) at 3 study sites in the Sierra San Pedro Mártir, Baja California, Mexico.

Site	Most prevalent species	Importance value	Distribution	Californian (%)	Sonoran (%)	Continental (%)
El Represo (21 species)	<i>Adenostoma fasciculatum</i>	42.7	Californian	38.1	38.1	14.3
	<i>Cylindropuntia californica rosarica</i>	29.2	Californian			
	<i>Eriodtyction angustifolium</i>	24.3	Sonoran			
	<i>Isocoma menziesii</i>	22.4	Californian			
	<i>Opuntia</i> cf., <i>phaeacantha</i>	19.4	Continental			
	<i>Gutierrezia sarothrae</i>	14.8	Continental			
San Miguel (24 species)	<i>Isocoma menziesii</i>	56.8	Californian	45.8	37.5	12.5
	<i>Artemisia tridentata</i>	30.9	Continental			
	<i>Eriogonum fasciculatum</i>	26.3	Continental			
	<i>Ambrosia camphorata</i>	17.8	Sonoran			
	<i>Prosopis glandulosa</i>	17.5	Sonoran			
	<i>Baccharis sarothrae</i>	13.1	Sonoran			
El Rincón (24 species)	<i>Ambrosia chenopodifolia</i>	45.5	Sonoran	37.5	54.2	4.2
	<i>Ambrosia camphorata</i>	35.4	Sonoran			
	<i>Viguiera laciniata</i>	21.2	Californian			
	<i>Opuntia tesajo</i>	20.0	Sonoran			
	<i>Pachycereus pringlei</i>	18.2	Sonoran			
	<i>Agave cerulata nelsolnii</i>	16.7	Californian			

¹ Percentages do not add to 100 because of the presence of one cosmopolitan taxon at each site and one unidentified taxon at El Represo.

The steepness of the gradient in species composition across the 3 sites was evidenced by a value of <0.1 in Jaccard's index of similarity (>90% dissimilarity) (López-Beltrán, 2003). Except for one transect each at El Rincón and San Miguel, the transects clustered as independent units at each site, emphasizing the dissimilarity in species composition across this transition (López-Beltrán, 2003).

Implications for Conservation—The Californian-Sonoran boundary zone that we studied is an example of a gradual biome transition defined by broad-scale climate features, likely related strongly to the timing and amounts of precipitation, and only weakly to temperature. A notable characteristic of biome transitions, clearly shown in the results of the present study, is higher biodiversity because of factors including enhanced patchiness, the presence of different microhabitats, and higher species-area relationships, especially where the ranges of species overlap (Gosz, 1992; Risser, 1995). This Californian-Sonoran biome boundary could be sensitive to changes in the global climate and, thus, worthy of long-term monitoring. *Erythea armata*, an elegant Baja California endemic, seems to be

particularly adapted to this biome transition and forms its own microhabitats: the oases of the southern Peninsular Range of the Californias.

The remoteness and inaccessibility of the blue fan palm oases has until now protected them from most human impacts, although grazing of domestic cattle has been practiced for at least a century. The oases are now threatened by changes in the Mexican land-tenure system and the accelerating economic development of the Mexico-USA boundary region. These oases represent an important touristic resource for Baja California, but much of the Sonoran Desert on the peninsula is already included in Protected Natural Areas, such as Valle de los Cirios and the Vizcaíno Biosphere Reserve. Thus, it is unlikely that the oases will be considered for additional governmental protection, and they should remain a priority for conservation by private and non-governmental organizations.

We thank C. Montes, J. Domínguez, B. Uhlig, and M. Necoechea for help with field work, and S. Lanham for providing unforgettable views from the air. We are grateful to J. M. Domínguez and J. Ponce for the graphics and artwork. This study was supported by

CICESE internal projects, and specimens were collected under Ministry of the Environment (SEMARNAT) permit NUM/SGPA/DVGS/03338. Specimens are held at the CICESE research plant collection.

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Submitted 3 March 2006. Accepted 5 October 2006.

Associate Editor was Chris Lauver.

APPENDIX—Inventoried vascular plant taxa from the Sierra San Pedro Mártir, Baja California, Mexico, listed by distributional affinity. Locations where taxa were recorded are indicated by 1, and absence is indicated by 0, in the sequence El Represo, San Miguel, El Rincón. Baja California endemics are indicated by +.

CALIFORNIAN TAXA ($n = 71$): *Adenostoma fasciculatum* 1 0 0; *Adolphia californica* 0 1 1; *Agave cerulata* ssp. *nelsonii* + 1 1 1; *Amorpha apiculata* + 0 1 1; *Arctostaphylos* cf. *pringlei* ssp. *drupacea* 1 1 0; *Artemisia californica* 0 1 1; *Astragalus douglasii* var. *glaberrimus* + 0 0 1; *Berberis higginsiae* 1 0 0; *Calystegia macrostegia* 0 1 0; *Camissonia californica* 0 1 0; *C. strigulosa* 0 1 0; *Carex spissa* 0 0 1; *Castilleja exserta* 1 0 0; *Ceanothus leucodermis* 1 0 0; *Cirsium occidentale* 1 1 0; *Croton californicus* 1 0 0; *Cylindropuntia alcahes* var. *mcgillii* + 0 1 1; *Cylindropuntia californica* var. *rosarica* + 1 1 1; *Dudleya* cf. *abramsii* ssp. *abramsii* 1 0 0; *Encelia californica* 0 0 1; *Epilobium canum* ssp. *canum* 0 1 0; *Ericameria brachylepis* 1 1 1; *Erigeron foliosus* 1 0 0; *Eriogonum elongatum* + 0 1 1; *E. wrightii* var. *membranaceum* 1 0 0; *Eriophyllum confertiflorum* 0 1 0; *Fraxinus trifoliata* + 0 1 0; *Galium angustifolium* 1 1 0; *Garrya veatchii* 1 0 0; *Geraea viscida* 1 0 0; *Heteromeles arbutifolia* 1 0 0; *Isocoma menziesii* 1 1 1; *Iva hayessiana* 0 1 1; *Juncus xiphioides* 1 1 1; *Juniperus californica* 1 1 0; *Lathyrus alefeldii* 0 1 1; *Lonicera subspicata* var. *demodata* 1 1 0; *Lotus* cf. *hamatus* 1 1 0; *L. scoparius* 0 0 1; *Lythrum californicum* 0 1 0; *Malosma laurina* 1 1 1; *Mammillaria dioica* 1 0 1; *Melica imperfecta* 1 1 1; *Mimulus cardinalis* 1 0 1; *Mirabilis californica* 0 0 1; *Nolina palmeri* + 1 0 0; *Oxitheca trilobata* 1 0 0; *Pellaea andromedifolia* 0 1 0; *P. mucronata* 1 1 1; *Penstemon centranthifolius* 1 1 0; *P. spectabilis* ssp. *subinteger* 0 1 1; *Phacelia parryi* 0 1 0; *Phlox austromontana* 1 0 0; *Pinus quadrifolia* 1 0 0; *Prunus ilicifolia* 1 0 0; *Pseudognaphalium microcephalum* 1 0 0; *P. violettii* 1 0 0; *Quercus palmeri* 1 0 0; *Rhamnus californica* 1 0 0; *R. crocea* 0 1 0; *Rhus ovata* 1 1 0; *Ribes quercetorum* 0 1 1; *Sakvia apiana* 1 1 1; *S. columbariae* 1 1 0; *Sellaginella bigelovii* 0 1 1; *Simmondsia chinensis* 1 1 1; *Solidago californica* 0 0 1; *Stephanomeria tenuifolia* 0 1 1; *Streptanthus campestris* 1 0 0; *Viguiera laciniata* 0 1 1. *Yucca whipplei* 1 0 1.

SONORAN TAXA ($n = 59$): *Acacia greggii* 0 1 1; *Acalypha californica* 1 1 1; *Adenophyllum porophylloides* 0 1 1; *Agave morani* + 1 0 0; *Ambrosia camphorata* 0 1 1; *A. chenopodifolia* 0 0 1; *Astragalus palmeri* 1 0 1; *Atriplex polycarpa* 0 0 1; *Baccharis sarothroides* 1 1 1; *Baileya multiradiata* 1 0 0;

Bebbia juncea 0 0 1; *Bernardia myricifolia* 1 0 0; *Brickellia frutescens* 1 0 1; *Bursera microphylla* 0 0 1; *Calliandra californica* + 0 0 1; *Chamaesyce melanadenia* 1 0 0; *C. micromera* 1 1 1; *Cylindropuntia cholla* + 0 0 1; *C. molesta* 0 0 1; *C. tesajo* 0 1 1; *Dalea bicolor* var. *orcuttiana* + 1 0 1; *Ditaxis lanceolata* 0 0 1; *Echinocereus engelmannii* 1 1 1; *Encelia farinosa* 1 0 1; *Ephedra aspera* 1 1 1; *E. californica* 1 1 0; *Eriodictyon angustifolium* 1 0 0; *Erythra armata* + 1 1 1; *Euphorbia tomentulosa* 0 1 1; *E. xantii* + 0 1 1; *Ferocactus gracilis* + 1 1 1; *Fouquieria columnaris* + 0 0 1; *F. splendens* 0 0 1; *Galium stellatum* 1 1 0; *Hymenoclelea monogyra* 1 0 0; *Hyptis emoryi* 0 0 1; *Ipomopsis tenuifolia* 1 0 0; *Justicia californica* 1 0 1; *Krameria erecta* 1 1 1; *Lophocereus schottii* 0 1 1; *Lotus* cf. *saluginosus* 1 1 0; *Lycium andersonii* 0 0 1; *Myrtillocactus cochal* + 0 0 1; *Nicolletia trifida* + 0 1 0; *Opuntia chlorotica* 1 1 0; *Pachycereus pringlei* 0 0 1; *Phacelia affinis* 1 0 0; *Phoradendron californicum* 1 0 0; *Prosopis glandulosa* 1 1 1; *Prunus fremontii* 1 1 1; *Quercus* cf. *ajoensis* 1 0 0; *Solanum hindsianum* 0 1 1; *Sphaeralea ambigua* 1 1 1; *Stenocereus gummosus* 0 0 1; *Stillingia linearifolia* 1 0 1; *Trixis angustifolia* 0 0 1; *T. californica* 0 0 1; *Viguiera triangularis* + 0 1 1; *Ziziphus obtusifolia* var. *canescens* 0 1 1.

CONTINENTAL TAXA ($n = 34$): *Amaranthus fimbriatus* 1 0 0; *Amsinckia intermedia* 0 1 0; *Anemopsis californica* 0 1 0; *Artemisia ludoviciana* ssp. *incompta* 1 0 0; *A. tridentata* 1 1 0; *Baccharis salicifolia* 1 1 1; *Cheilanthes covillei* 0 1 1; *Cryptantha intermedia* 1 0 0; *Datura innoxia* 1 1 1; *Dichelostemma capitatum* 0 1 0; *Distichlis spicata* 0 1 1; *Eriastrum diffusum* 1 0 0; *Eriogonum fasciculatum* var. *polifolium* 1 1 1; *Eriophyllum wallacei* 1 0 0; *Frankenia salina* 0 0 1; *Gnaphalium palustre* 0 0 1; *Gutierrezia sarothrae* 1 1 0; *Heliotropium curassavicum* var. *oculatum* 0 0 1; *Larrea tridentata* 0 0 1; *Lepidium lasiocarpum* var. *lasiocarpum* 1 1 0; *Lotus rigidus* 1 1 1; *Mimulus guttatus* 1 0 1; *Opuntia* cf. *phaeacantha* 1 1 1; *Phoradendron cerotinum* ssp. *tomentosum* 1 0 0; *Phoradendron* cf. *densum* 1 0 0; *Pinus monophylla* 1 0 0; *Populus fremontii* 1 1 0; *Porophyllum gracile* 0 1 1; *Quercus turbinella* 1 0 0; *Ranunculus cymbalaria* var. *saximontanus* 0 0 1; *Rhus trilobata* 1 0 0; *Salix laevigata* 1 1 1; *Scirpus americanus* 0 1 1; *Yucca schidigera* 1 1 1.

COSMOPOLITAN TAXA ($n = 6$): *Artemisia dracunculus* 1 0 0; *Azolla filiculoides* 0 1 0; *Hydrocotyle verticillata* 0 1 0; *Juncus acutus* 0 1 1; *J. balticus* 1 0 0; *Typha domingensis* 0 1 1.

INTRODUCED TAXA ($n = 10$): *Apium graveolens* 0 0 1; *Chenopodium murale* 1 1 1; *Cotula coronopifolia* 0 1 1; *Erodium cicutarium* 1 0 0; *Malva parviflora* 0 0 1; *Marrubium vulgare* 0 0 1; *Medicago polymorpha* 1 1 1; *Rorippa nasturtium-aquaticum* 0 1 1; *Sonchus oleraceus* 1 0 1; *Tamarix ramosissima* 0 1 1.

SPECIES NOT IDENTIFIED ($n = 13$): *Abutilon* sp. 0 1 1; *Adiantum* sp. 0 0 1; *Brassica* sp. 0 1 0; *Chorizanthe* sp. 1 0 0; *Cuscuta* sp. 0 1 0; *Dudleya* species A 0 1 0; *Dudleya* species B 1 0 1; *Linanthus* sp. 1 0 0; *Lotus* sp. 1 0 0; *Lupinus* sp. 0 0 1; *Lycium* sp. 1 0 0; *Matelea* sp. 0 1 0; *Quercus* sp. 0 1 0.